# Double Helicity Asymmetry of Inclusive $\pi^0$ Production in Polarized $pp$ Collisions at $\sqrt{s} = 62.4$ GeV

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**Abstract.** The proton spin structure is not understood yet and there has remained large uncertainty on $\Delta g$, the gluon spin contribution to the proton. Double helicity asymmetry ($A_{LL}$) of $\pi^0$ production in polarized $pp$ collisions is used to constrain $\Delta g$. In this report, preliminary results of $A_{LL}$ of $\pi^0$ in $pp$ collisions at $\sqrt{s} = 62.4$ GeV measured by PHENIX experiment in 2006 is presented. It can probe higer $x$ region than the previously reported $\pi^0 A_{LL}$ at $\sqrt{s} = 200$ GeV thanks to the lower center of mass energy.

**Keywords:** Spin, Proton spin structure
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## INTRODUCTION

The so-called "proton spin crisis," initiated by the results from the polarized deep inelastic scattering experiments, has triggered wide effort towards the understanding of proton spin. Despite the wide efforts, there has remained large uncertainty on $\Delta g$, the gluon spin contribution to the proton. RHIC, the world's first polarized proton-proton collider, provides us an opportunity to directly probe gluons in the proton. Double helicity asymmetry ($A_{LL}$) of inclusive $\pi^0$ production in polarized $pp$ collisions is sensitive to $\Delta g$ because $\pi^0$ production is dominated by gluon-gluon and quark-gluon interactions in the measured $p_T$ range. PHENIX has previously reported $\pi^0 A_{LL}$ in $pp$ collisions at $\sqrt{s} = 200$ GeV [1] which is based on the data taken in 2005 (Run5) and it indicates that $\Delta g$ is not large.[2] But a large uncertainty remains for large Bjorken $x$ $(> 0.1)$ and more statistics are needed. During the run in 2006 (Run6), one-week data taking was performed at $\sqrt{s} = 62.4$ GeV. Spin rotator commissioning was successful and we had longitudinally polarized collisions. [3] Even in this short data taking with a small integrated luminosity of 60 nb$^{-1}$ and the average polarization of 48%, the data has a big advantage to cover the larger $x$ region thanks to the lower center of mass energy. According to a pertubative QCD (pQCD) calculation, collisions at $\sqrt{s} = 62.4$ GeV has $\sim 300$ times larger cross-section than that at $\sqrt{s} = 200$ GeV at fixed $x_T = 2p_T/\sqrt{s}$. It corresponds to 10 times larger statistics than the previously reported $\pi^0 A_{LL}$ which is based on the integrated luminosity of 1.8 pb$^{-1}$ with average polarization of 47%.

$A_{LL}$ is defined as

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \quad (1)$$

where $\sigma_{++(+-)}$ is the production cross-section in like (unlike) helicity collisions. Experimentally, $A_{LL}$ is calculated as

$$A_{LL} = \frac{1}{|P_B||P_Y|}\frac{N_{++}-RN_{+-}}{N_{++}+RN_{+-}}, \;\; R = \frac{L_{++}}{L_{+-}} \tag{2}$$

where $P_{B(Y)}$ denotes the beam polarization, $N^{++(+-)}$ is the $\pi^0$ yield and $L^{++(+-)}$ is the luminosity in like (unlike) helicity collisions. $R$ is the relative luminosity.

## EXPERIMENT

The stable polarization direction of RHIC beam is transverse. Then it is rotated to get longitudinally polarized collisions just before the PHENIX interaction point. PHENIX local polarimeter[3] confirms that the beam is longitudinal by measuring $A_N$ of forward neutrons.

PHENIX has Beam-Beam Counter (BBC) which covers $3.0 < |\eta| < 3.9$ and Zero Degree Calorimeter (ZDC) which covers very forward angle ($\pm$2mrad).[4] These two detectors serve as independent luminosity measure. We used BBC counts to measure relative luminosity $R$ in equation (2) and its uncertainty is estimated by comparing to ZDC counts. It is found to be $\delta R = 1.3\times 10^{-3}$. This corresponds to $\delta A_{LL} = 2.8\times 10^{-3}$ which is less than the statistical uncertainty.

PHENIX has the ability to clearly identify $\pi^0$ through its gamma decay by using an Electro-Magnetic Calorimeter (EMCal) which covers the central rapidity region ($|\eta| < 0.35$) and half in azimuth angle. [4] PHENIX also has an excellent gamma triggering capability (the threshold is 0.8 GeV or 1.4 GeV) which makes high-statistics $\pi^0$ measurement feasible.[5] EMCal based trigger without coincidence with BBC is used because the collision trigger efficiency based on BBC is low at $\sqrt{s} = 62.4$ GeV.

The systematic uncertainty is evaluated by the bunch shuffling technique,[6] and it is found to be negligible.

## $A_{LL}$ CALCULATION

$\pi^0 A_{LL}$ ($A_{LL}^{\pi^0}$) is calculated by subtracting $A_{LL}^{\mathrm{BG}}$ from $A_{LL}^{\pi^0+\mathrm{BG}}$. $A_{LL}^{\pi^0+\mathrm{BG}}$ is the asymmetry for the diphoton invariant-mass range of 112 MeV/$c^2$-162 MeV/$c^2$ (under the $\pi^0$ peak). $A_{LL}^{\mathrm{BG}}$ is the asymmetry for the range of 177 MeV/$c^2$-217 MeV/$c^2$ (higher side band).

Figure 1 shows the diphoton invariant mass spectra. The lower mass peak corresponds to background from hadrons and cosmic particles, which induce EMCal clusters with more complicated structure, each of them are then splitted on several ones. This peak roughly corresponds to two EMCal cell separation between two clusters, which moves to higher mass with increasing cluster pair $p_T$. Since we used EMCal based trigger without coincidence with collision trigger at $\sqrt{s} = 62.4$ GeV, the cosmic background is prominent unlike in data at $\sqrt{s} = 200$ GeV. The contribution of such background under $\pi^0$ peak is negligible in the measured $p_T$ range. Since it does affect the lower side band, the $A_{LL}^{\pi^0+\mathrm{BG}}$ estimation was done based only on the higher side band. The subtraction is

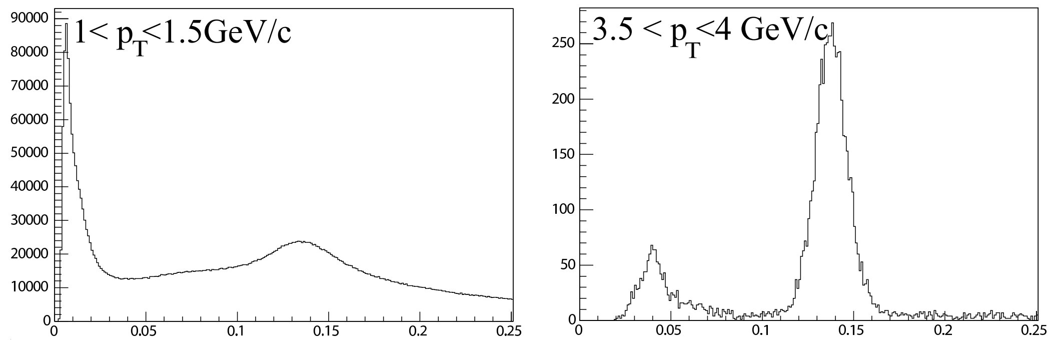


**FIGURE 1.** Diphoton invariant mass spectra.

done by using the following formula.

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+\mathrm{BG}} - rA_{LL}^{\mathrm{BG}}}{1-r} \tag{3}$$

where $r$ is the background fraction.

## RESULTS

Figure 2 shows the Run 6 results of $\pi^0 A_{LL}$ as a function of $p_T$. $A_{LL}$ is consistent with zero over the measured $p_T$ region. Detailed offline analysis on beam polarization is not provided yet by the RHIC polarimeter group. Thus online values are used and systematic uncertainty of 20% is assigned for a single beam polarization measurement. It introduces scaling uncertainty of 40% on $A_{LL}$. Theory curves based on pQCD using four proton spin models are also shown.[7] The theory is based on pQCD; thus it is important to test pQCD applicability at $\sqrt{s} = 62.4$ GeV. To test pQCD applicability, analysis on $\pi^0$ cross-section is on-going. With our cross section result, we will be able to discuss our $A_{LL}$ result further by comparing with pQCD calculations. Figure 3 shows the Run 6 results of $\pi^0 A_{LL}$ as a function of $x_T$ together with Run 5 results. A clear statistical improvement can be seen in the large $x_T$ region.

## SUMMARY

During the RHIC run in 2006, $\pi^0 A_{LL}$ at $\sqrt{s} = 62.4$ GeV was measured with the PHENIX detector. Preliminary results of $\pi^0 A_{LL}$ at $\sqrt{s} = 62.4$ GeV with integrated luminosity of 60 nb$^{-1}$ and the average polarization of 48% are presented. There is a clear statistical improvement in the large $x_T$ regin compared to the Run5 preliminary results at $\sqrt{s} =$ 200 GeV with integrated luminosity of 1.8pb$^{-1}$ and the average polarization of 47%. To extract the gluon spin contribution to the proton, it is important to test pQCD applicability at $\sqrt{s} = 62.4$ GeV. Analysis on cross-section is on-going to test pQCD at this energy. With our cross section result, we will be able to discuss our $A_{LL}$ result further by comparing with pQCD calculations.

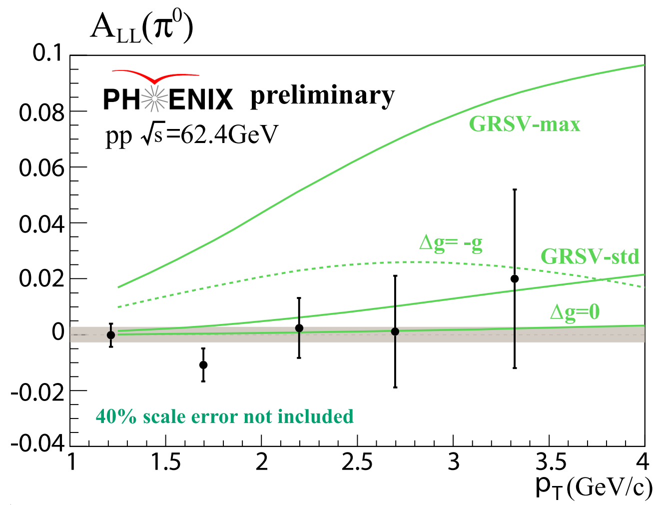


**FIGURE 2.** $\pi^0 A_{LL}$ as a function of $p_T$. The error bar denotes statistical uncertainty. Gray band denotes systematic error from relative luminosity.

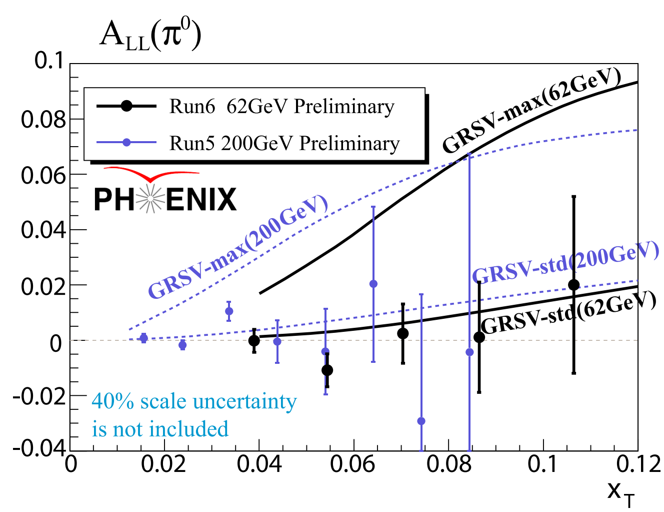


**FIGURE 3.** $\pi^0 A_{LL}$ as a function of $x_T$.

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